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A1R322 A1R324

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(54) Injection moulding process with periodic force application

(57) An injection moulding process for moulding a material in a mould O having a mould cavity P and at least one channel U/V communicating with the mould cavity P, each channel U/V entering the mould at a respective mould inlet Q/R includes the steps of heating inner surface areas of the mould to a temperature above the heat distortion temperature of the material; supplying the molten material into the mould O by way of at least one channel U/V and subjecting the molten material to a propelling force, sufficient to propel it through the channel into the mould O; causing the molten material in the mould O to solidify; applying periodic forces to the material in the mould O at a plurality of spaced-apart regions, first and second of the regions I, J being located either side of molten material in the mould cavity P, the periodic force being applied with a difference in phase so as to cause shear of molten material within the mould cavity P between the first and second regions; cooling the mould below the heat distortion temperature of the resin while or after applying the periodic force; and then opening the mould, and removing the moulded article. The shearing may be caused by two power pistons or by one such piston and a screw feeder (figure 10 - not shown). The pistons may hydraulically, spring or mechanically operated.

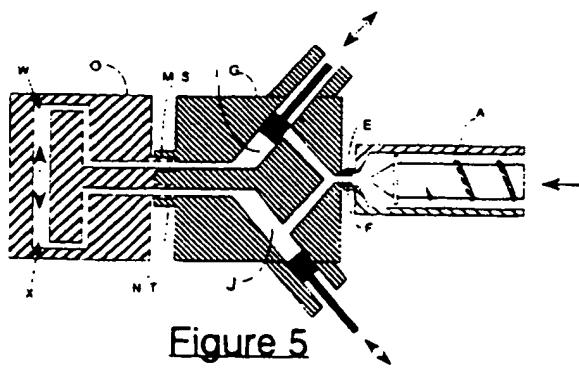


Figure 5

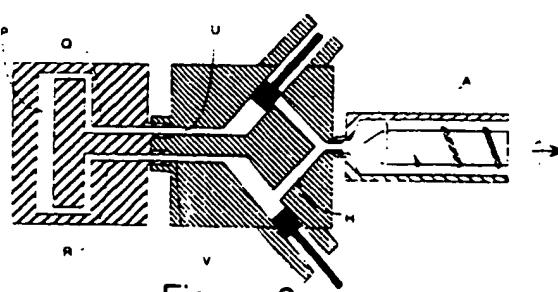


Figure 6

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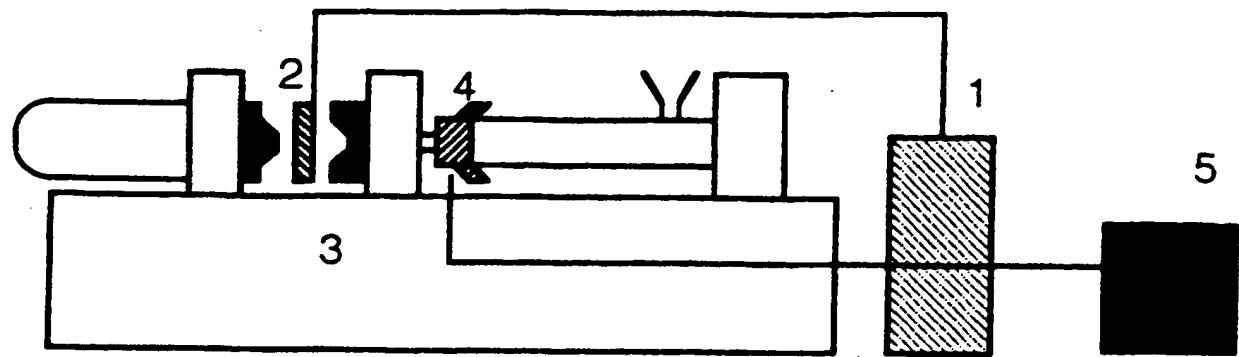


Figure 1

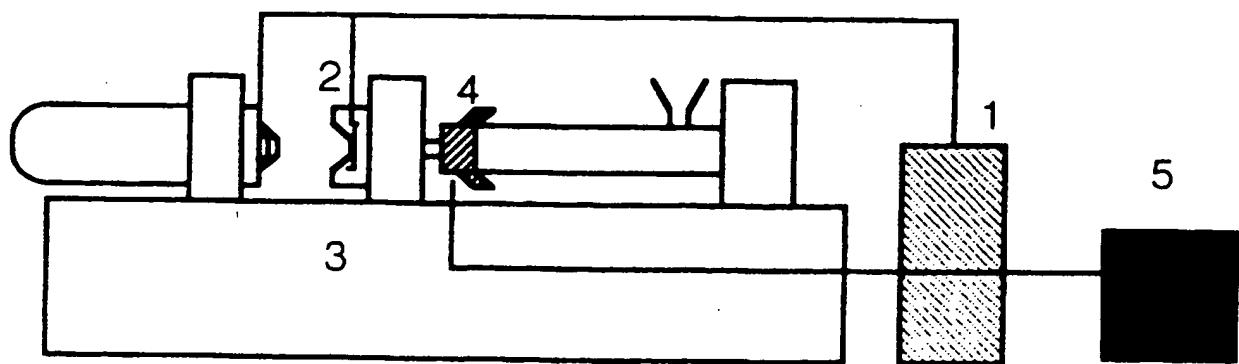
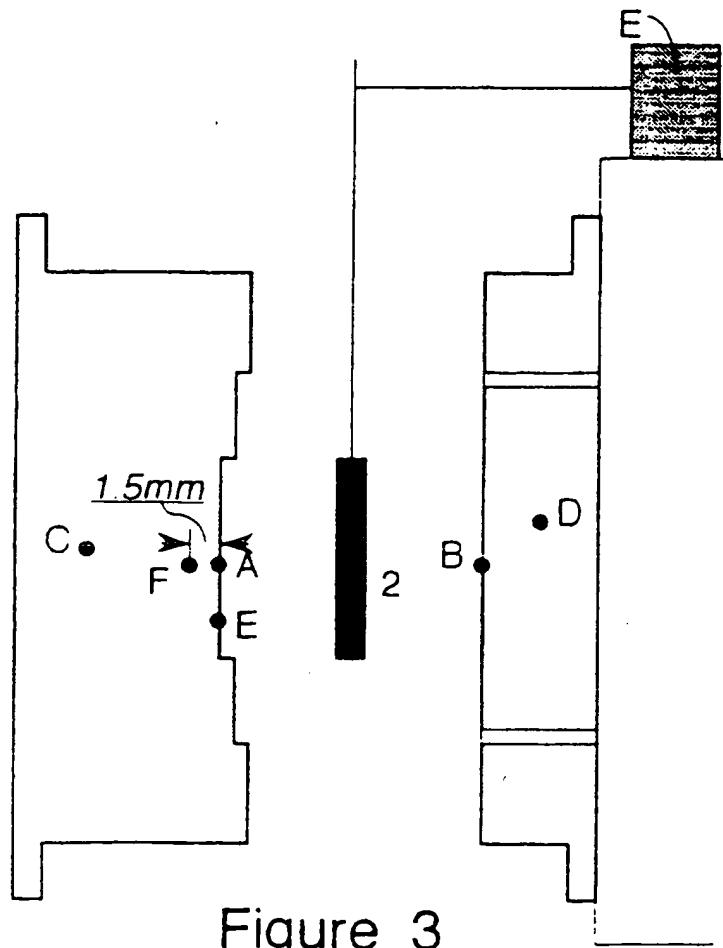


Figure 2



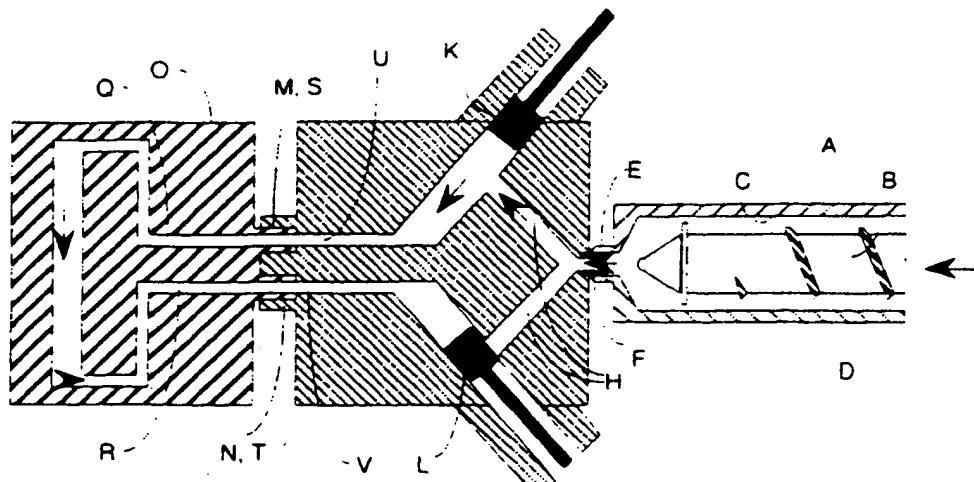


Figure 4

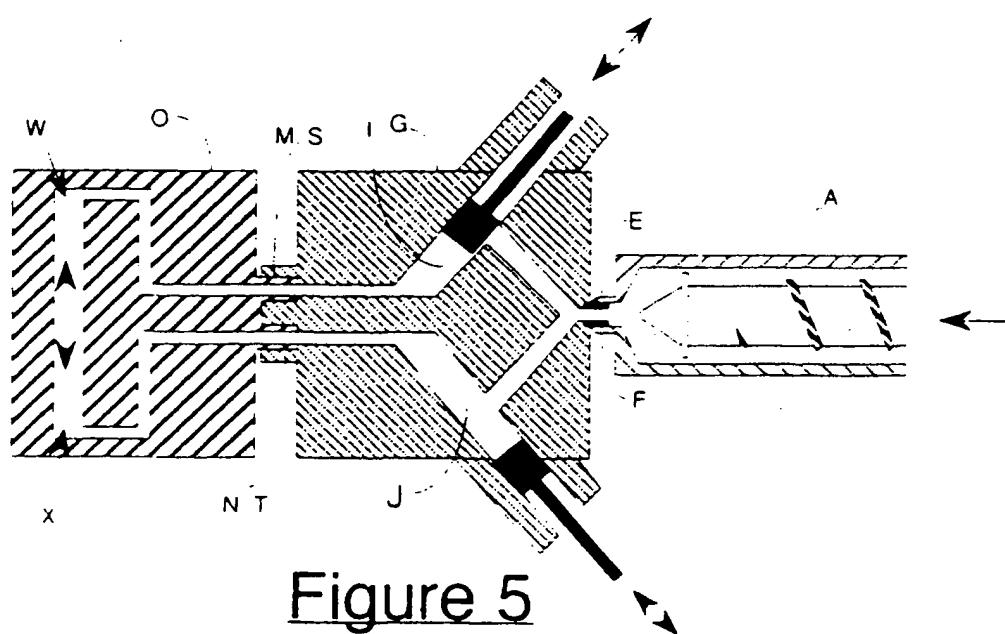


Figure 5

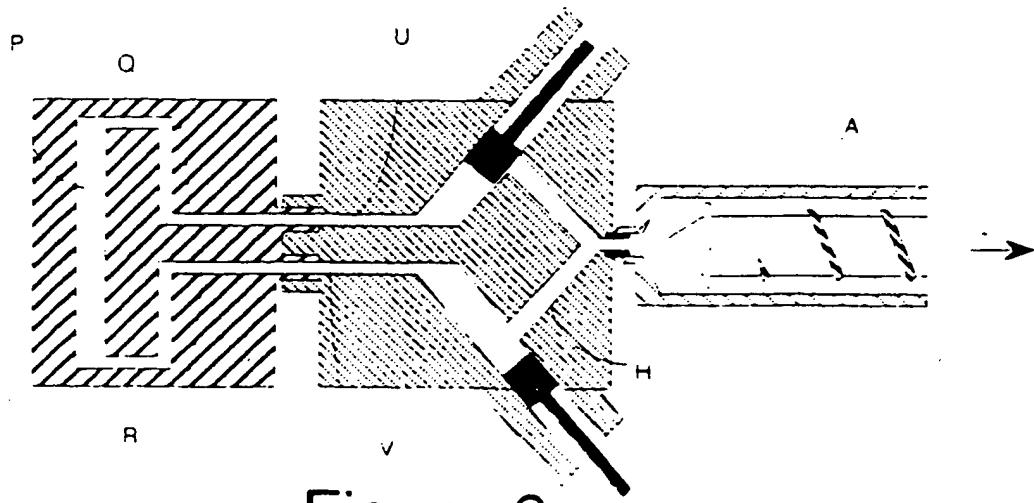


Figure 6

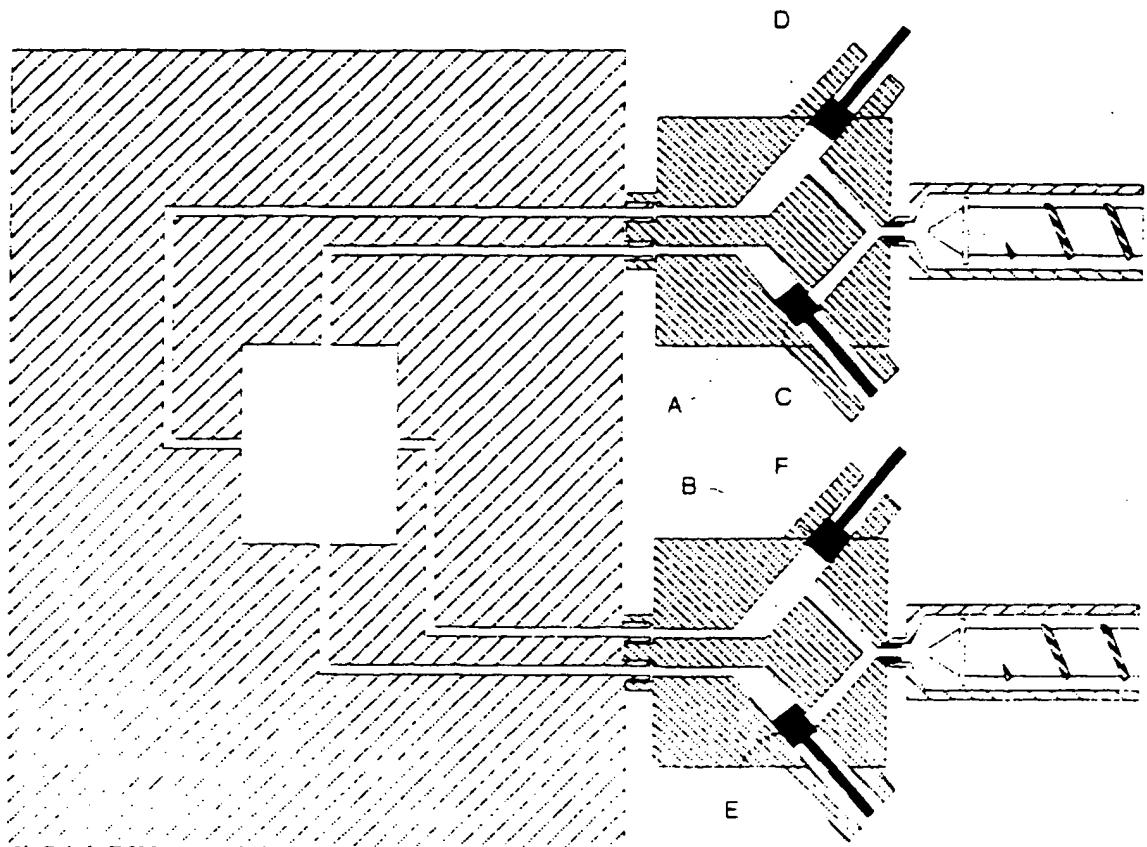


Figure 7

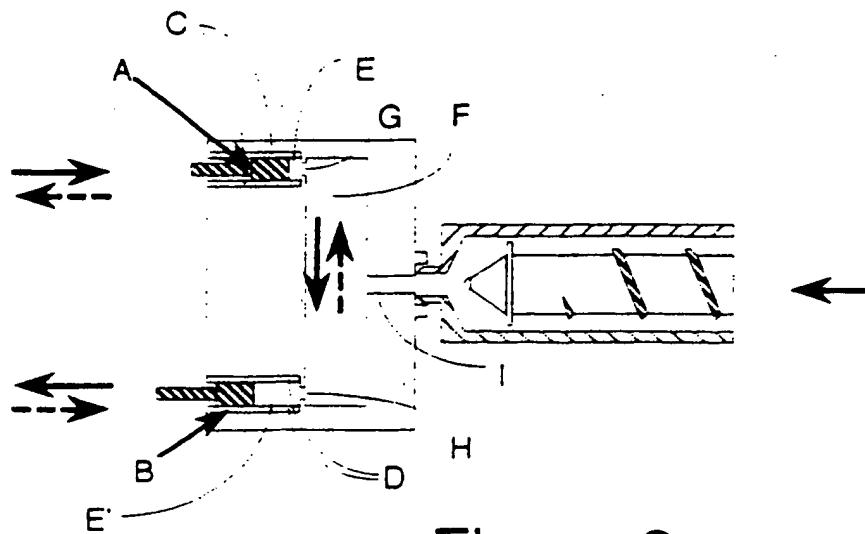


Figure 8

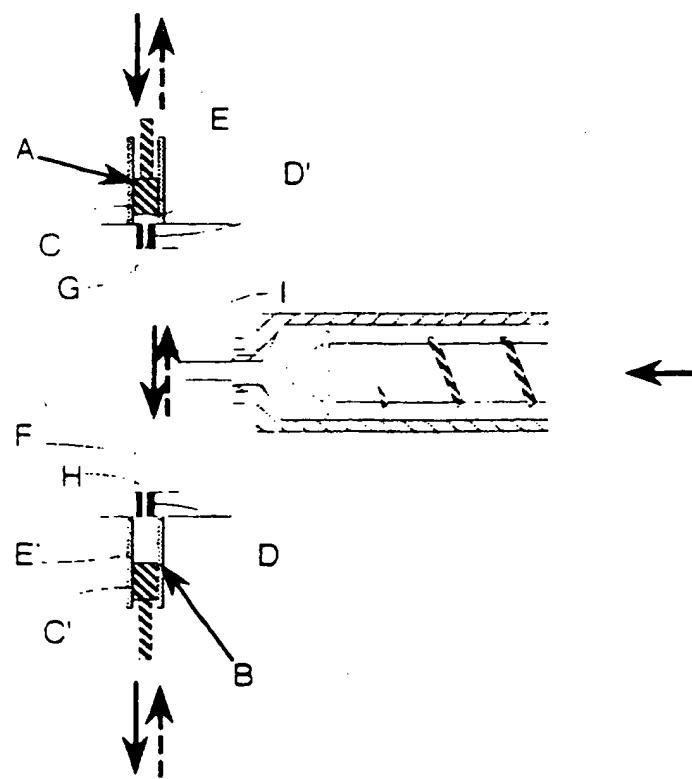


Figure 9

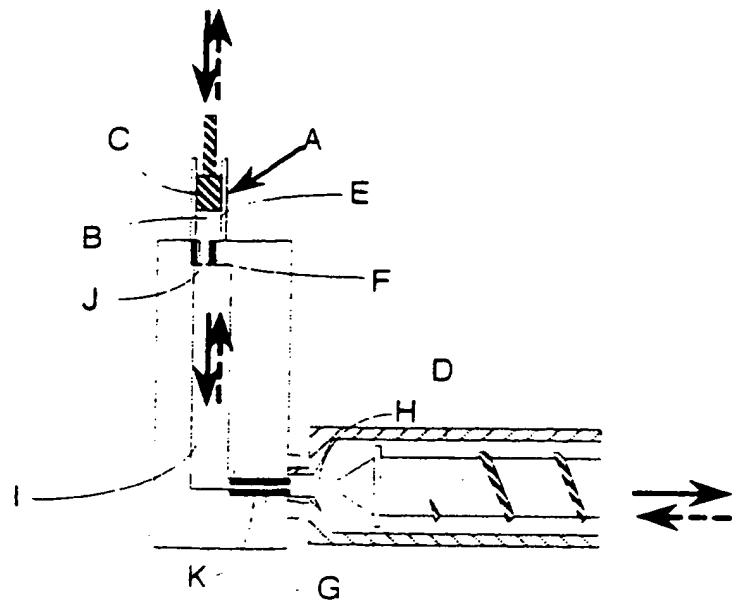


Figure 10

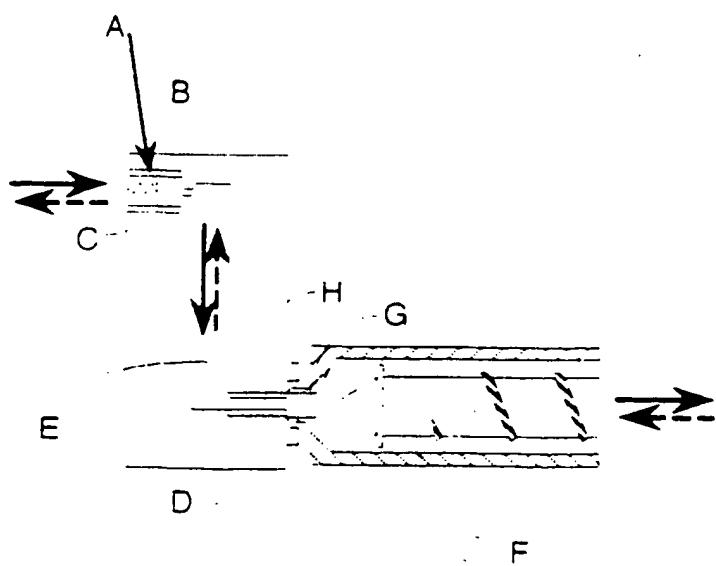
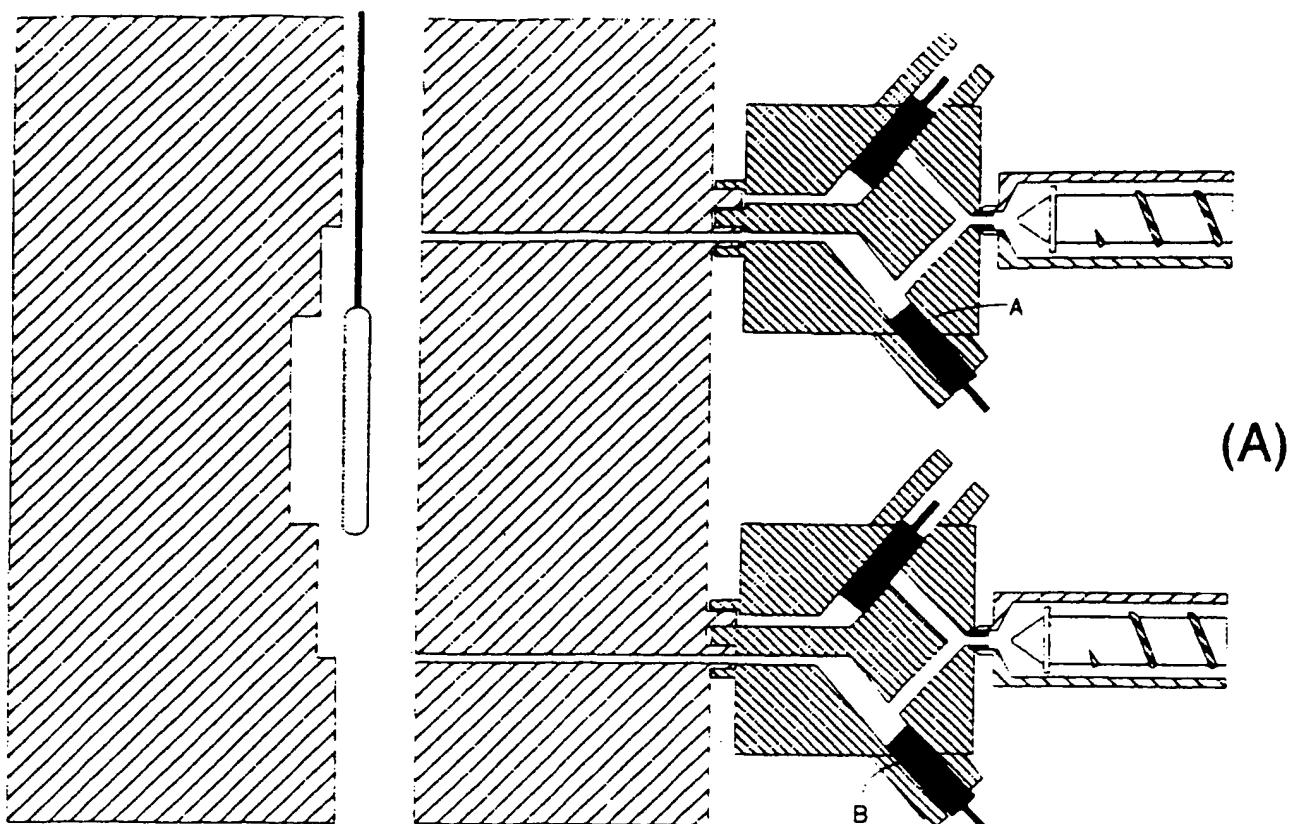
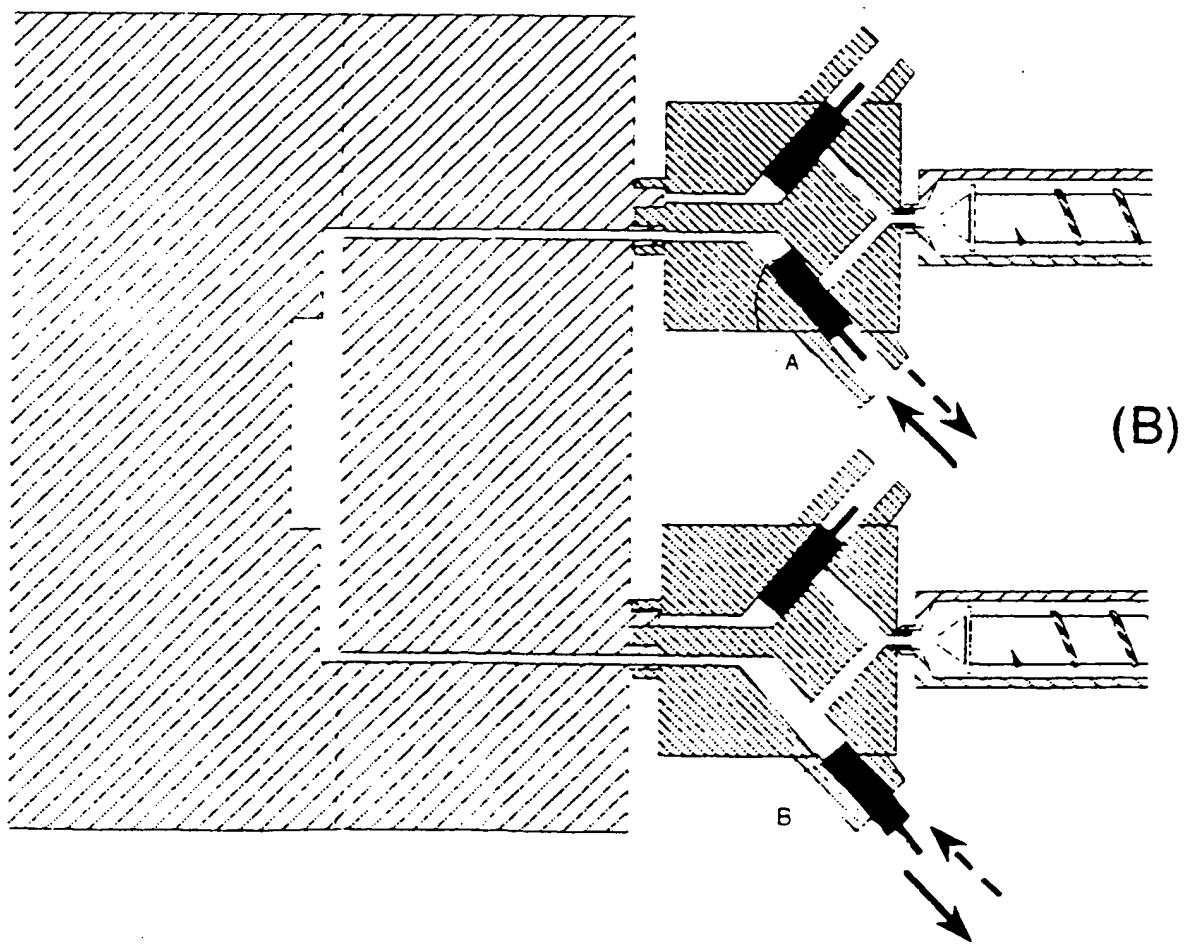


Figure 11



(A)



(B)

Figure 12

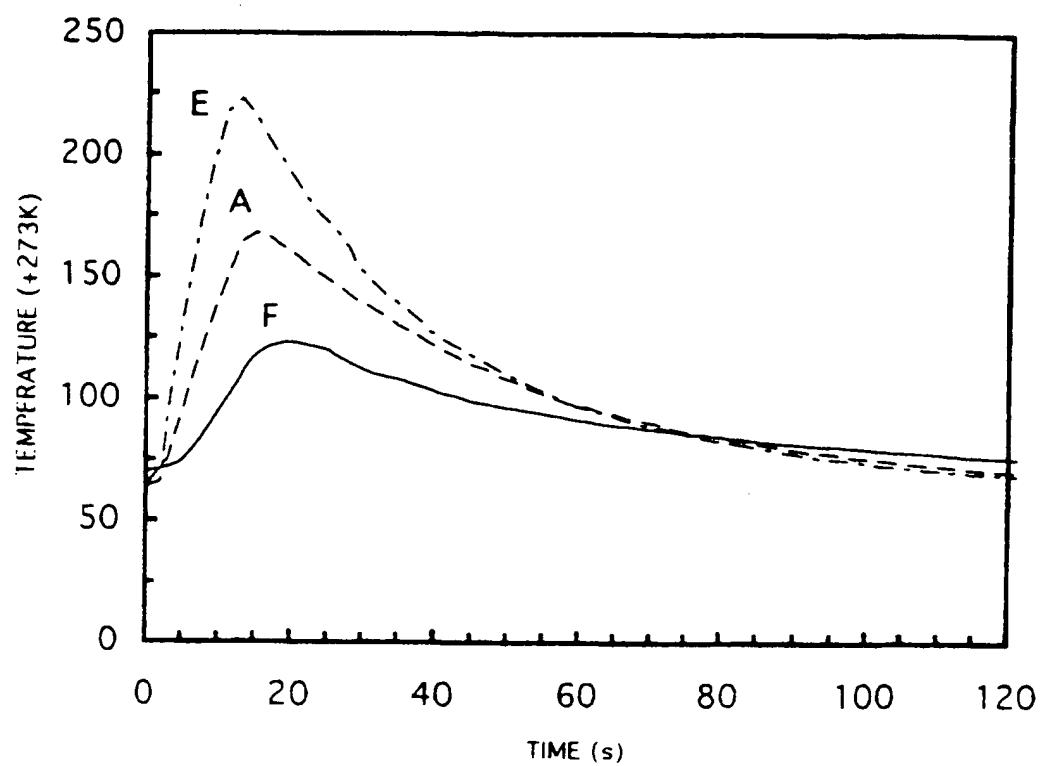


Figure 13

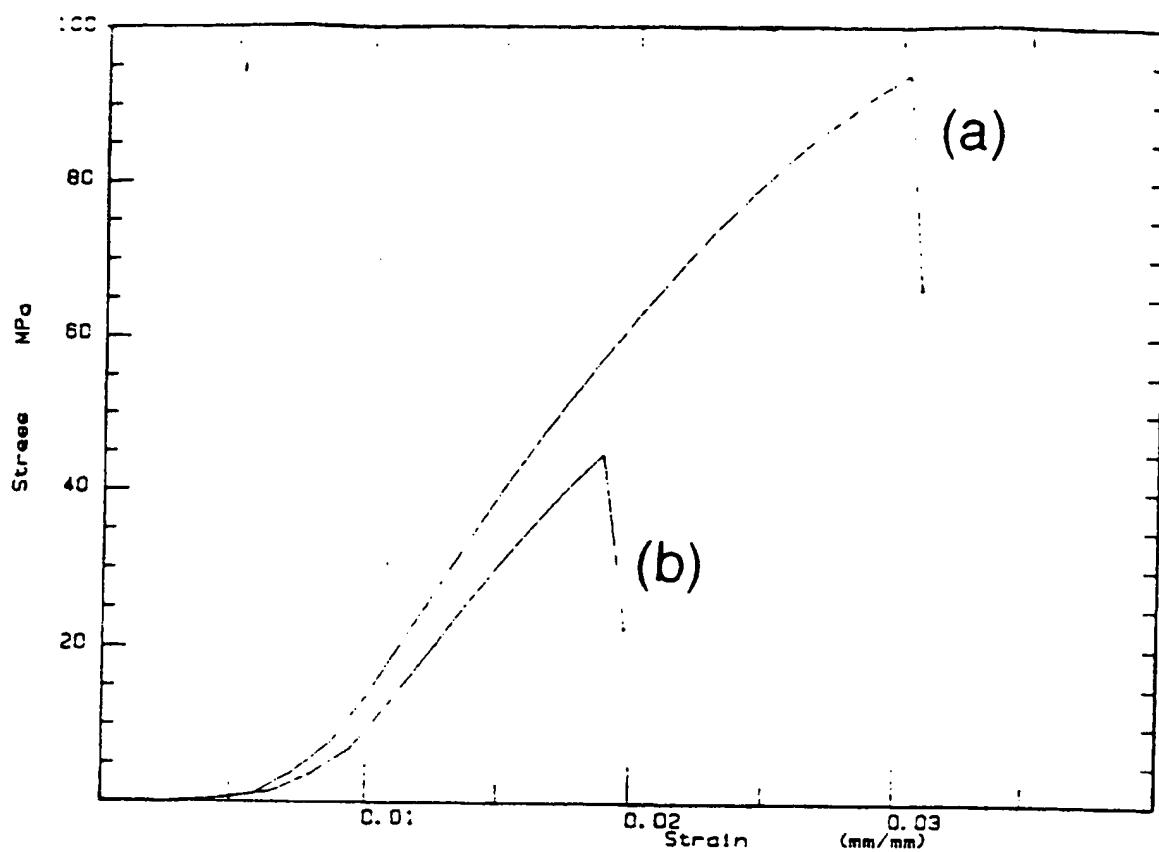


Figure 14

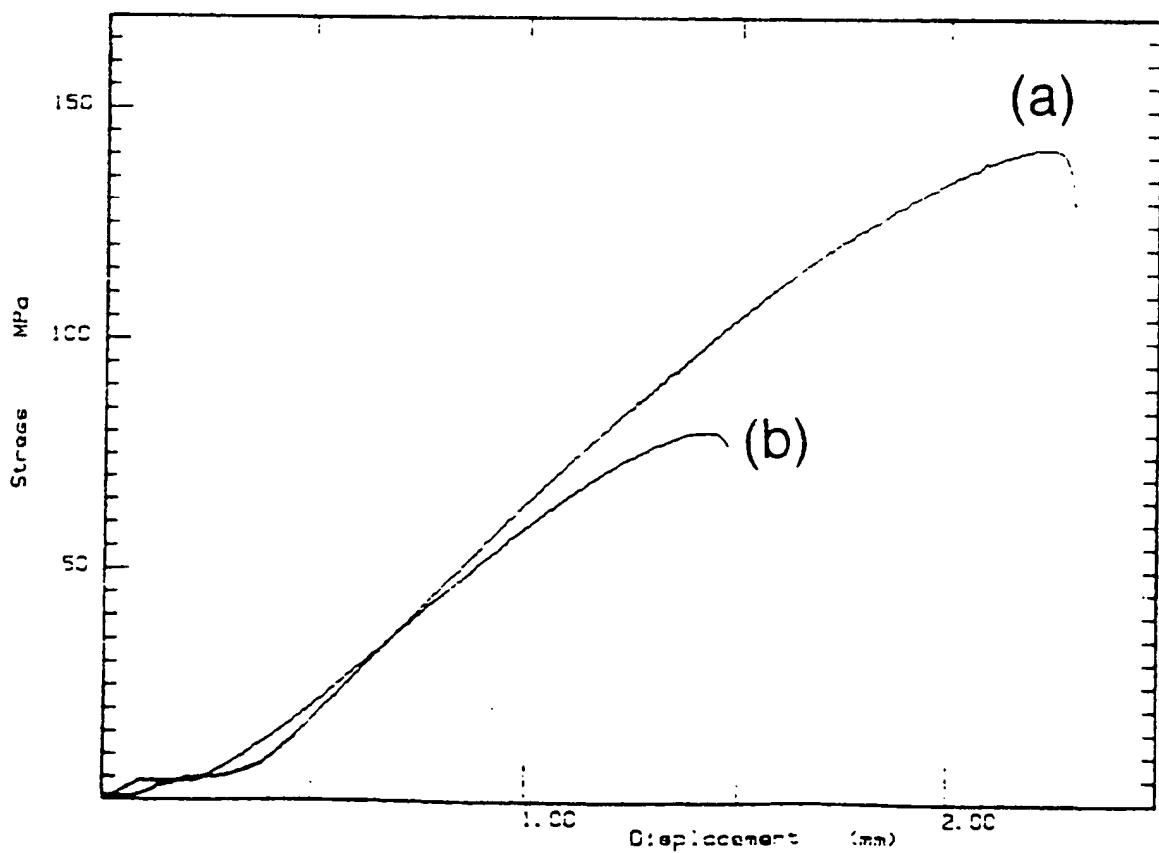


Figure 15

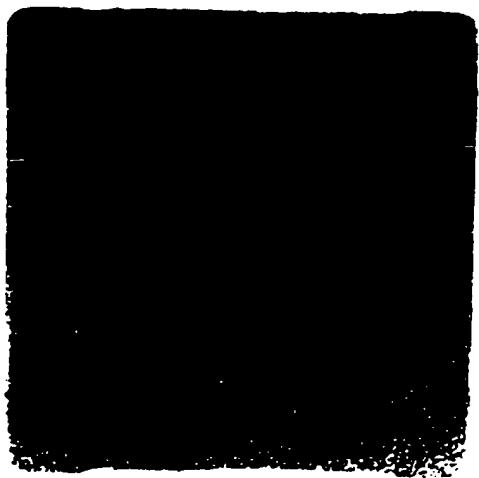


Figure 16

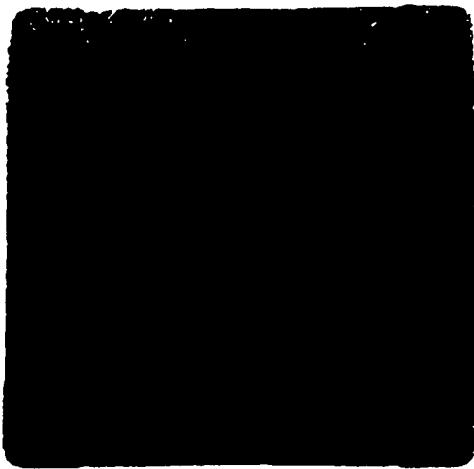


Figure 17-(a)

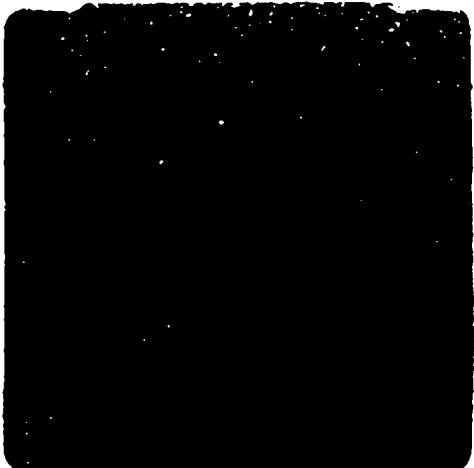


Figure 17-(b)



Figure 17-(c)

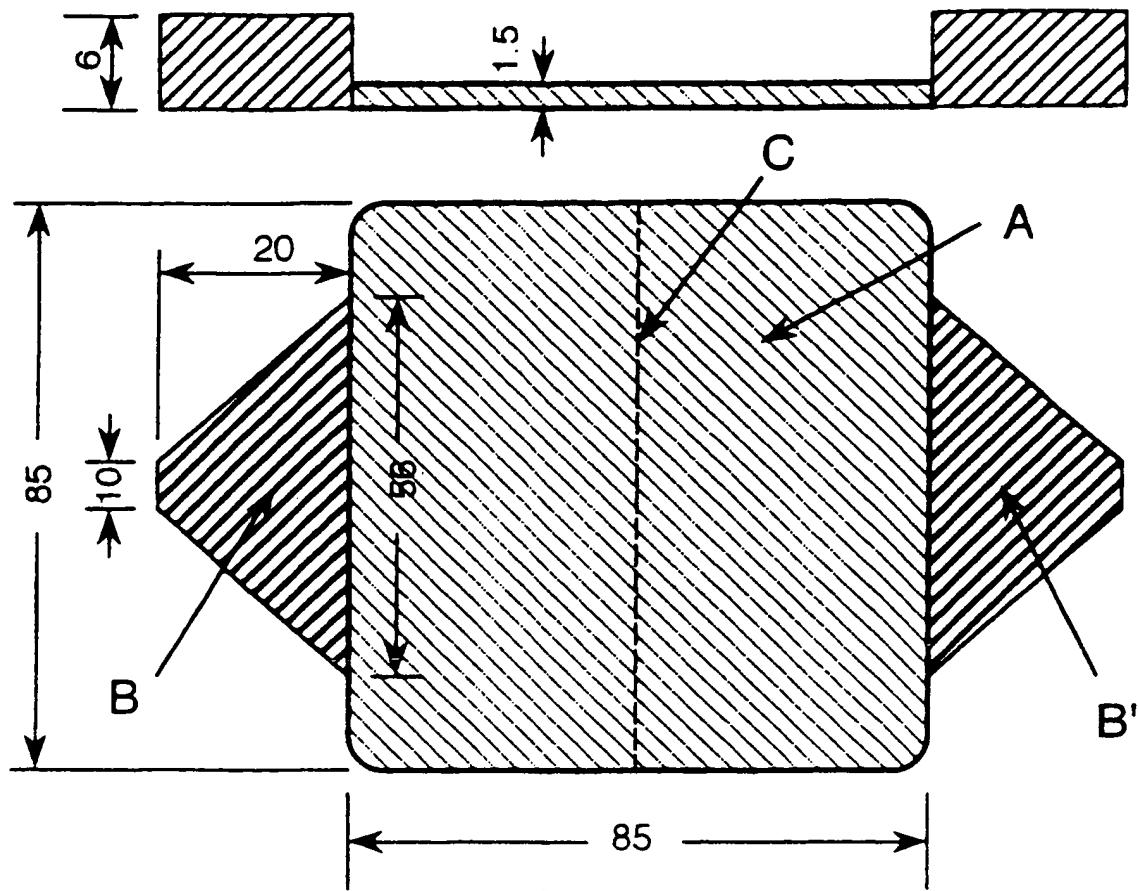


Figure 18

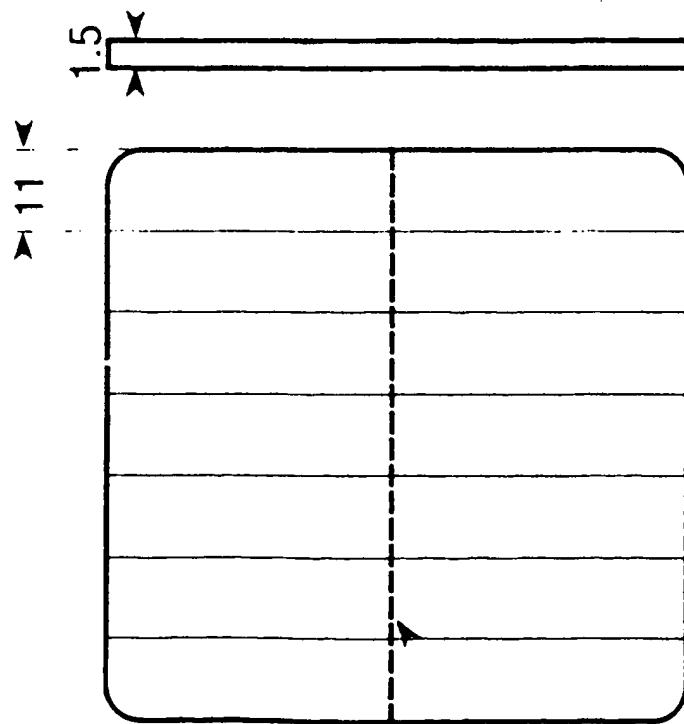


Figure 19

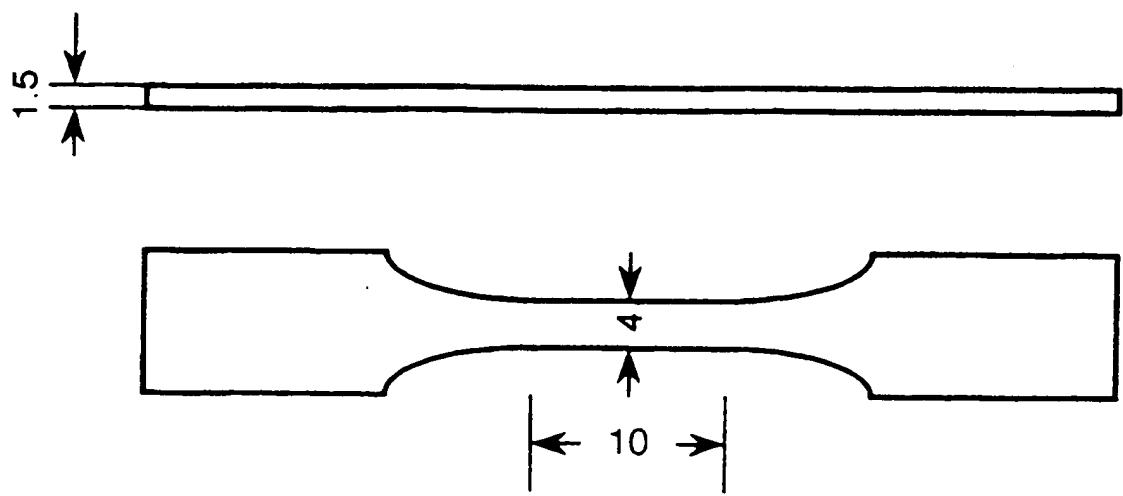


Figure 20

MOULDING PROCESS

. 1 -

The present invention relates to an injection moulding process which provides for a moulded article whose microstructure is controlled. The invention also relates to injection moulded articles produced from molten material containing at least one kind of thermoplastic resin, and which exhibit improved appearance and mechanical properties.

Heretofore, conventional injection moulding of thermoplastics resin has, in general, been based on a technique, in which a resin mixture is moulded in a metal mould by utilising the plasticity of the thermoplastic resin. The thermoplastic resin is caused to melt and is injected in to the mould, under a static holding pressure, and is then solidified in the mould by cooling it to obtain the moulded article. Thus, it is necessary to cool the moulded resin mixture to a temperature below the heat distortion temperature of the resin employed, in order to attain solidification of the resin mixture, so as to release and remove the moulded article from the mould in a satisfactory manner. When the moulded article is produced by the above-mentioned conventional moulding, there may sometimes be problems which relate to appearance and mechanical properties.

The first problem relative to appearance may occur with thermoplastic resins which contain reinforcing materials and/or fillers such as glass fibre, mica and metals. The reason is that the temperature of the metal mould is held usually below the heat distortion temperature of the resin employed. Also it is current practise to cool the metal mould to a temperature above the dew point by using a refrigerant, in order to increase productivity. The molten thermoplastic resin mixture, upon contact with the cold surface of the metal mould, is cooled abruptly and rapidly loses its ability to flow near the surface of the mould, whereby the impression of the mould surface is greatly

impaired, and results in a considerable irregularity on the surface of the moulded article.

The elevation of the temperature of the metal mould has been proposed as a measure for preventing premature solidification of the resin mixture.

However, an increase in the temperature of a metal mould will naturally require a longer cooling time, and this may result in the moulded article being taken out of the mould, while still incompletely solid and thus exhibiting poor dimensional stability. Therefore, in actual practice, the temperature of the metal mould is adjusted to a temperature that is a compromise for the adverse effects of these contradictory conditions.

An effective method for improving the injection moulding art, is proposed in GB-B-2,081,171, in which the inner surfaces of the metal mould are pre-heated by high-frequency induction heating. With this art, the mould temperature in injection moulding can be controlled. However, though the skin layer of the moulded article is improved using this technology, it is difficult to control the micromorphology of the core layer of the moulded article. Moreover it is difficult to improve the appearance of weld line marks in moulded articles containing metal flake, such as moulded articles of transparent ABS resin with aluminium flake as filler.

The presence of internal weld lines in articles moulded from thermoplastic resin may also result in a substantial reduction in mechanical properties. It is well known that the properties, notably mechanical properties such as tensile modulus and strength, of a thermoplastics material, may be enhanced in a given direction by causing the material to be oriented in that direction. Many processes have now been devised for accomplishing this enhancement of mechanical properties either by forming the material in the mass ab initio in

an oriented state, or by subsequently imparting plastic strain to the solid material. All such processes provide, oriented products of comparatively simple, and constant, cross-section: examples are fibre and film, including biaxially oriented film; and rod, tube and sheet stock. No comparable benefit has hitherto been available for thermoplastic materials moulded from the melt into articles of complex geometry.

In relation to the conventional injection moulding process, the molten mass of mouldable material is injected into the mould cavity from one feeding point and the subsequent packing force is also applied at this single point. For certain requirements of mould design, in particular moulds with long flow paths and moulds with variations in cavity wall thickness, the single feed may be split so that the cavity can be filled satisfactorily from a number of feeds, or gating points. This practice results in the formation of internal weld lines within the moulded part, at the positions where the various melt flow fronts from the multiple gate points meet. It has been shown that the presence of weld lines can cause undesirable reductions in the mechanical properties of the moulded article.

The GB-B-2,170,142 describes a process in which a filled molten material in the mould cavity can be sheared during solidification. With this art, the level of control over the microstructure throughout the bulk material is extremely high, resulting in enhancement of the article's physical properties. However, though the bulk material can be controlled by this technology, it is difficult to control the micromorphology of the skin layer of the moulded article, because the skin layer solidifies as soon as the molten material contacts the cold surface of the mould. As a result, the impression of the mould surface is greatly impaired and results in a considerable irregularity on the surface of the moulded article.

The present invention seeks to provide improved injection moulding which can permit the manufacture of injection moulded articles exhibiting superior surface characteristics.

The present invention also seeks to provide injection moulded articles with improved mechanical properties, for example thermoplastic resin compositions containing reinforcing materials and/or fillers.

According to the present invention, there is provided an injection moulding process for moulding a material in a mould having a mould cavity and at least one channel communicating with the mould cavity, each channel entering the mould at a respective mould inlet, the process including the steps of: heating inner surface areas of the mould to a temperature above the heat distortion temperature of the material; supplying the molten material into the mould by way of at least one channel and subjecting the molten material to a propelling force, sufficient to propel it through the channel into the mould; causing the molten material in the mould to solidify; applying periodic forces to the material in the mould at a plurality of spaced-apart regions, first and second of the regions being located either side of molten material in the mould cavity, the periodic force being applied with a difference in phase so as to cause shear of molten material within the mould cavity between the first and second regions; cooling the mould below the heat distortion temperature of the resin while or after applying the periodic force; and then opening the mould, and removing the moulded article.

The inner surface of the metal mould is preferably selectively heated only superficially to a temperature above the heat distortion temperature of the material using high frequency induction heating. In some embodiments, the whole molten material, both the skin and the core layer can be caused to flow

after the initial mould filling. And then the molten material is caused to solidify while maintaining a shear force and/or a packing force, and is then demoulded.

Such instantaneous heating may be achieved by heating methods such as infrared heating, introducing a high temperature fluid in the mould, laser beam, and so on. However the most suitable instantaneous heating can be effected by use of a special heating method of high-frequency induction heating. In the preferred embodiment, the temperature in the skin layer of the mould inner surface is elevated at a fast rate. The actual rate of heat elevation is determined by taking into account of the actual heat processing temperature of the resin employed, the dimensions of the moulded product, and the mould release temperature. It is recommended, however, to heat to a predetermined temperature at a heat elevation rate of 80°C per minute or more, preferably $480^{\circ}\text{C}/\text{min}$. or higher and most preferably at $1200^{\circ}\text{C}/\text{min}$. By employing such instantaneous heating, only a thin layer over the inner surface of the metal mould can be heated to the processing temperature of the resin, above its heat distortion temperature, without the heat being conducted into the interior of the metal mould and without causing the whole metal mould to be heated, so as to accommodate the prompt heat removal at time of cooling. Thus, it is possible to shorten the moulding cycle with simultaneous attainment of higher surface quality of the moulded articles. Furthermore, by employing the high-frequency induction heating, it is possible to eliminate possible contamination of the metal mould by the heating fluid mentioned. Other advantages of the use of high-frequency induction heating may be recited as follows:

- (a) facilitate temperature control,
- (b) enabling either homogeneous heating over the whole surface of the mould or selective heating, including local heating of specific areas additional

to the above mentioned superficial heating, thus enabling by design the selective heating of either the whole mould or a local part of the mould,

- (c) eliminating adverse effects of heat on the operators,
- (d) offers a push-button automatic operation.

Additional benefit is seen in subjecting the supplied molten material to a shear force by applying a periodic force to each of a plurality of regions of the molten material, there being a difference in the periodic force applied to at least two different such regions effective to cause shear of the molten material at least between the two such regions.

While such a process may be effected with the periodic forces being in phase, provided that the frequency of one such force is an integral multiple of the other(s), it may be particularly desirable that the periodic force applied to at least two different regions of the molten material are of the same frequency, especially where the periodic force applied to at least two different regions of the molten material are out of phase, for example 180° out of phase, with each other.

The periodic force may be applied to a plurality of regions of the molten, mouldable material by dividing the supply of the material into a plurality of channels, for example two channels, and applying, by means of a piston variably reciprocable in a cylinder communicating with the channel, a periodic force thereto. The force will be positive when the piston tends to compress the molten, mouldable material and negative when it tends to permit expansion of the molten, mouldable material.

Forces substantially higher than those generally used in moulding processes may be employed to enhance the force to about 4820 bar (70,000 p.s.i.).

typically from 2750 bar to 5520 bar (40,000 to 80,000 p.s.i.).

The periodic force would be applied for at least the minimum time consistent with obtaining the controlled cooling and degree of orientation required. This depends principally on the mould cavity dimensions and the nature of the mouldable composition.

Immediately prior to solidification of the molten, mouldable materials, the periodic forces may be applied in phase to provide auxiliary packing pressure to the mould cavity. Furthermore, sequences wherein the periodic forces are effective to cause shear may be interposed with sequences wherein the forces provide auxiliary packing pressure.

The process disclosed herein can be used for all kinds of thermoplastic resins, such as styrene resin such as polystyrene (PS), rubber reinforced styrene base resin such as high impact polystyrene (HIPS) and medium impact polystyrene (MIPS), styrene/acrylonitrile resin (SAN resin), butyl acrylate rubber/acrylonitrile/styrene copolymer (AAS), ethylene-propylene rubber/acrylonitrile/styrene copolymer (AES), chlorinated polyethylene/acrylonitrile/styrene copolymer (ACS), ABS resins including acrylonitrile/butadiene/styrene copolymer, acrylonitrile/butadiene/styrene/ α -methyl styrene copolymer and acrylonitrile/methyl methacrylate/butadiene/styrene copolymer, and so on. These may be acrylic resins such as polymethyl methacrylate (PMMA), and so on. These may be polyolefine resins such as low density polyethylene (LDPE), high density polyethylene(HDPE), polypropylene (PP), and so on. These may be vinyl chloride resin such as polyvinyl chloride (PVC), polyvinylidene chloride (PVDC), ethylene vinylacetate vinylchloride copolymer, ethylene vynylchloride copolymer, and so on. These may be polyester resin such as polyethylene terephthalate (PETP or PET).

polybutylene terephthalate (PBTP or PBT), and so on. These may be polycarbonate resin such as polycarbonate (PC), modified polycarbonate, and so on. These may be polyamide resin such as polyamide 66, polyamide 6, polyamide 46, and so on. These may be polyacetal resins (POM) such as polyoxymethylene copolymer, polyoxymethylene homopolymer. These may be other engineering plastics and super engineering plastics such as polyether sulphone (PES), polyether imide (PEI), thermoplastic polyimide (TPI), polyetherketone (PEK), polyetheretherketone (PEEK), polyphenylene sulphide (PPS), polyphenylene ether (PPE), polysulphone (PSU), and so on. These may be cellulosics such as cellulose acetate (CA), cellulose acetate butyrate (CAB), ethyl cellulose (EC), and so on. These may be liquid crystals polymers (LCP) resin such as liquid crystalline polyester, liquid crystalline aromatic polyester, and so on. These may be thermoplastic elastomer such as thermoplastic-elastomeric polyurethanes (TPU), thermoplastic-elastomeric styrene-butadienes (SBC), thermoplastic-elastomeric polyolefins (TPO), thermoplastic-elastomeric polyesters (TPEE), thermoplastic-elastomeric polyvinyl chlorides (TPVC), thermoplastic-elastomeric polyamides (TPAE), and so on. These may be materials which synthesise the above mentioned thermoplastic resins in process of moulding in the present invention. Blends of one or more of thermoplastic resins may be moulded by the process. The thermoplastics may contain fillers and/or additives. --

The process can also be used for all kinds of thermosetting resins which are cured under sufficient heat, such as phenol formaldehyde resin (PF), urea formaldehyde resin (UF), melamine-formaldehyde resin (MF), unsaturated polyester (UP), epoxide resin (EP), diallyl phthalate resin (DAP), silicone (SI), polyurethane (PUR), polyimide (PI), and so on. The thermosetting resin may contain fillers and/or additives. The thermosetting resin may contain catalyst and/or curing agent.

The filler to be incorporated in the thermoplastic resin composition and/or mouldable materials can include those of inorganic nature, for example glass fibre, glass beads, calcium carbonate, mica, asbestos, and so on and powder, hollow and flake material of metals such as iron, copper, zinc and aluminium, as well as oxides and hydroxides of these metals.

The process can also be used for sandwich moulding, in which the injection of core material causes a skin material (such as paint or other surface finish) to be spread evenly over the surface. The modification of the moulded part will be caused by the action of the shearing means on both the skin layer material and core material.

An embodiment of the present invention is described below, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows in schematic illustration an embodiment of injecting moulding apparatus;

Figure 2 is another embodiment comparable to Figure 1;

Figure 3 shows the portion of a metal mould employing a high frequency inductor inserted within the mould cavity, in vertical section;

Figures 4 to 6, inclusive, are schematic plans, axially-sectioned along the flow path, of a manifold for the apparatus shown in Figures 1 and 2, representing different times in the moulding cycle, the manifold is shown in situ interposed between the mould and the injection moulding machine;

Figure 7 is another embodiment comparable to Figures 4 to 6 when a twin barrel injection moulding machine is used;

Figure 8 represents a variant wherein devices for applying a periodic shear force are inserted within the mould cavity;

Figure 9 represents a variant wherein devices for applying a periodic shear force are located on the mould and not between molten material supply

means and mould;

Figure 10 represents a variant wherein a device for applying a periodic shear force is located on or within the mould, and not between the molten material supply means and the mould, and used in combination with an oscillating screw on the primary injection unit;

Figure 11 represents a variant wherein a device for the production of the periodic shearing forces installed on/in the mould is operated by a means other than by hydraulic power;

Figure 12 shows an illustration of mould and shear control devices for a twin barrel injection machine in accordance with Examples 1, 2 and 3 and References 1, 2 and 3;

Figure 13 is a chart showing examples of standard in-mould temperature profiles;

Figure 14 represents stress-strain curves for the tensile testing of mouldings prepared in accordance with Example 2 and Reference 2 as given on the following pages;

Figure 15 represents stress-displacement curves for the flexural testing of mouldings prepared in accordance with Example 2 Reference 2 as given on the following pages;

Figure 16 is a photograph of the surface appearance in accordance with Example 3;

Figure 17 show photographs of the surface appearances in accordance with Reference 3;

Figure 18 illustrates the size and shape of the moulded article used in Examples;

Figure 19 illustrates the sizes and shapes of the flexural test specimens used in Examples 1 and 2;

Figure 20 illustrates the sizes and shapes of the tensile test bars used in Examples 1 and 2.

As shown in Figure 1 and Figure 2, the embodiment of apparatus shown consists of an injection moulding machine 3, a high-frequency induction heating device 2, and a shear control device 4.

The high frequency induction heating device is composed of a high-frequency oscillator 1 and an inductance coil (inductor) 2 installed near the inner surface of the metal mould and connected to the oscillator 1 and controller 1. The oscillator may be separated from the controller. The shear control device is composed of a manifold 4, a hydraulic pump 5 and controller (not shown). In the embodiment shown in Figures 1 and 3, the inductor is inserted in the mould cavity by being placed between the two mould halves of the split metal mould by robot operation. In the embodiment shown in Figure 2, the inductor 2 is built in to the mould.

In Figure 3, the mould segment and the inductor of Figure 1 are shown in an enlarged view. The inductor is placed between the stationary mould half and the moving mould half by the robot E. When it is energised by high frequency oscillations, then the temperature in the surface layer of the metal mould (at points A, B and E) is increased steeply and the temperature in the bulk of the mould (at points C and D) is almost unchanged. The temperature-time dependence shown in Figure 13 illustrates by way of a example the course of temperature at positions A, E and F in Figure 3 of the metal mould after high-frequency heating in accordance with Example 1. The split metal mould is opened, when the temperature of the mould surface reaches a predetermined temperature. The inductor 2 is withdrawn from the space between the fixed mould half and movable mould half by the robot E. Subsequently, the split mould is closed again to carry out the injection moulding of thermoplastic resin mixture in a conventional manner.

Additional details of the high-frequency induction heating device and the mould component are disclosed in patent specification GB-B-2,081,171.

In figure 4, the injection moulding machine A shown comprises a drivable injection screw B mounted for rotation about, and for oscillation along, its axis within a substantially coaxially-extending elongated cavity C of a cylindrical, heatable barrel D. Downstream from the screw the cavity communicates within a nozzle E lined with a bush F, and upstream with a feed hopper (not shown) containing polymer feedstock.

In the apparatus shown in Figures 4 to 6 of the drawings, nozzle E mates with a manifold G and the bush F communicates with an axially-symmetric, bifurcated conduit H, each branch of which leads upwardly into cylinders I, J in each of which is opposedly mounted an axially-slidable, drivable pistons K, L, respectively. In turn, each cylinder communicates by way of channels U, V with-axially aligned twin nozzles M, N which constitute the outlets of manifold G.

The twin nozzles M, N mate with a mould O (shown closed) which comprises a double sprued, double gated bar mould cavity P and sprues Q, R the inlets S, T which connect with the twin manifold outlet nozzles M and N respectively.

In use, at start-up the mould tooling is assembled; demoulding agent is applied to the surfaces defining the mould cavity; the mould is then closed and brought to temperature, for example from 20 °C to 80 °C. Granular polymer feedstock is fed from the feed hopper into the elongated cavity and heated by the cylindrical barrel heater (not shown). The molten polymer feedstock is further heated, plasticised, and rendered substantially homogeneous by rotation

of the injection screw. When the molten polymer feedstock is determined to be of the right viscosity, rotation and downstream translation of the injection screw exerts a propelling force to inject the molten material into the mould cavity which is preheated or being heated at the predetermined temperature by high frequency induction heating. The molten polymer feedstock enters the manifold and passes, successively, through cylinder I; nozzle M; sprue Q; mould cavity P; sprue R; nozzle N and into cylinder J where further transport is prevented by piston L. When the mould cavity, sprues and manifold are filled with molten polymer feedstock the injection screw is stopped from rotating but is held at a position to provide a constant packing force downstream thereof. It can thus be seen that the first function of the manifold is to split the single feed (ex nozzle E) into the desired number of separate feeds. In this illustrated example the feed has been split into two identical channels U and V.

Pistons K and L are then reciprocated (see Figure 5) at the same frequency, but out of phase with each other by 180° . This reciprocation generates periodic forces and so maintains the molten polymer feedstock in the mould cavity, sprues and manifold channel U, V under continual, oscillating shear which generates heat and which, by appropriate microprocessor control (not shown), enables the rate of cooling of the polymer feedstock to be controlled. In effect, periodic forces are exerted upon the material in the mould cavity P, first at the end region W where sprue Q enters, and then at the opposite end at region X where sprue R enters, region W, X being indicated in Figure 5. The molten polymer feedstock in the mould cavity is thus continuously sheared by repetitive injection of molten polymer feedstock from cylinders I and J. Shrinkage of the polymer feedstock on cooling is compensated for by further molten polymer feedstock necessarily being fed into the mould cavity from the manifold (and also from the elongated cavity) during the first reciprocation

cycle.

In a preferred embodiment, this shear force is applied as the mould becomes full. For example, as one side of molten material reaches a junction point, its progress through the mould is substantially halted by appropriate control of the relevant piston. Material approaching the junction point from the other side thereof then has shear imparted thereto, by control of the relevant piston, such that shear forces are produced within the material as the portions thereof come into contact with one another. It has been found that this embodiment, which effectively applies shear forces just before the mould cavity becomes full, can efficiently remove the junction between the material portions. This can assist in reducing the time during which the surface of the mould cavity needs to be heated and thereby also the cooling time required.

At the end of the first reciprocation cycle (when a substantial proportion of the polymer feedstock in the mould cavity has solidified but while that in the gates is still molten) the pistons are, in a second reciprocation cycle, reciprocated in phase with each other so that the periodic forces which they apply now constitute packing forces auxiliary to the propelling force exerted by the injection screw, until the polymer feedstock in the gate has solidified.

In the preferred embodiment, the internal surfaces of the mould are heated to a substantially greater temperature than provided in prior art induction heated systems. More specifically, rather than being heated to the distortion temperature of the material, which provides a good surface finish, the surfaces of the mould cavity are heated to the melt processing temperature of the material to be moulded. It has been found that processing at such a temperature can remove signs of junctions between portions of material in the mould, which was not possible with prior art induction heating processes.

This effect can also be obtained, it has been found, at temperatures slightly less than the melt processing temperature. Typical processing temperatures are around two times the distortion temperatures previously used. It has also been found that this does not adversely affect the surface finish.

The mould is then removed from the manifold; the moulded polymer feedstock is demoulded; and the injection screw is translated upstream ready for the next injection mould cycle.

It may be desirable, in successive injection moulding cycles, to alternate injection of the molten polymer feedstock between cylinders I and J in order to prevent polymer feedstock becoming trapped in a nozzle and thereby becoming degraded.

Figure 7 shows another embodiment of moulding apparatus. In this case two manifolds A and B are attached to each injection unit on a two colour injection moulding machine. Alternating successively during solidification between the out of phase operation of pistons C and E and then D and F produces a laminated structure of preferred fibre orientation, the number of laminates and the preferred orientation of fibres within each laminate being determined by the sequence of operation of the pistons C, D, E and F.

Other details of the shear control device are disclosed in the patent specification GB-B-2,170,142.

Figure 8 shows another embodiment of moulding apparatus. In this case two manifolds A and B are incorporated in a mould and each are in contact with the mould cavity F, by the gates and runner systems G and H neither of which are coincident with the material supply runner and gate system I. The

manifold may be equipped with heaters C and D to assist the movement of molten materials. The volume (E, E') which is stocked with molten material is of a size which would produce a macroscopic shear and displacement of the molten material between E and E' when the volume of E and E' is displaced between the locations of the two gates.

In the embodiment of moulding apparatus shown in Figure 9, two manifolds A and B are attached to a mould and are each in contact with the mould cavity, F, by the gate and runner systems G and H, neither of which is coincident with the material supply runner and gate system I. The manifolds may be equipped with heaters C,C' or/and D,D' to assist in the movement of molten materials. The volume (E, E') which is stocked with molten material is of a size which would produce a macroscopic shear and displacement of the molten material between E and E' when the volume of E and E' is displaced between the locations of the two gates.

Figure 10 shows another embodiment of moulding apparatus in which a single manifold A is attached to or in a mould and is in contact with the mould cavity I, by a runner and gate system J, which is not coincident with the runner and gate system K of the supply means to the cylinder of the injection moulding machine. The manifold may be equipped with heaters E and/or F to assist the movement of molten materials. The volume B which is stocked with molten material is of a size which would produce a macroscopic shear and displacement of the molten material between B and H when the volume of B and H is displaced between the locations of the two gates. The molten material can be sheared by using the power of piston C and injection cylinder D. A heater G may be placed around the sprue and/or runner to prevent the material solidifying in the feed channel, J, connecting the shearing means D and the mould cavity I.

The embodiment shown in Figure 11 includes a device A which is not operated by hydraulic power is attached to or incorporated in a mould. For example a spring loaded piston, a screw driven or other mechanical device. The device may be equipped with heater C to assist the movement of the molten materials. The volume B which is stocked with molten material is of a size which would produce a macroscopic shear and displacement of the molten material between B and G when the volume of B and G is displaced between the locations of the two gates. A heater D may be placed around the sprue and/or runner to prevent the material solidifying in the feed channel, H, connecting the shearing means F and the mould cavity E.

An advantage of the embodiments shown in Figures 8 to 11 is that the same machine head can be used because the shear inducing devices (e.g. pistons) are provided as appropriate on the mould tool. There can thus be a significant saving in cost and moulding efficiency. Moreover, with the locations of the shear inducing devices shown in the embodiments of Figures 8 to 11, there is greater selectivity in locations for the introduction of shear into the molten material in the mould, greater effectiveness in terms of the speed at which shear can be produced in regions of the molten material and less pressure required due to the closeness of the shear inducing devices to the mould cavity. These advantages can lead to an increase in the speed at which the material can be treated and therefore a reduction in the time during which the walls of the mould cavity need to be above or at the material processing temperature.

The moulding process can be further speeded up by introducing cooling within the mould tool, such as by cooling channels and the like.

There follow some Examples of processes for moulding materials, which are

given for the purpose of illustration only.

EXAMPLE 1

In this Example, the injection moulding machine, the high-frequency induction heating and shear control devices were arranged essentially as is shown in Figure 1 and Figure 12. The position of high-frequency induction heating device is shown in (A) of Figure 12, and the arrangement for applying periodic forces is shown in (B) of Figure 12.

A SAN resin composition containing 20% by weight of glass fibre was injection moulded by using a twin barrel injection moulding machine. A split mould made of steel was used which provided for moulding a flat square piece A having a thickness of 1.5mm (Figure 18) through opposing fan gates B and B' each measuring 56, 10x20x6 mm as shown in Figure 18.

The inductor was placed between the mould halves and energised up to a high frequency output of 20KHz at 15KW for 12 seconds.

The temperatures of the injection barrels were adjusted so as to obtain a resin mixture temperature of 240°C. Before injecting the resin mixture into the mould, the inductor prepared as above was lowered between the two mould halves by robot operation. The distances between the inductor and mould surfaces was 8 mm. After activation the oscillations at 20 KHz at 15KW for 12 seconds, the split mould was retracted to draw out the inductor before it was closed again. Then, the molten SAN resin composition containing glass fibre was injected into the mould through the manifold at an injection pressure of 100 bar. The mould cavity was filled through the fan gates to produce a weld line at the centre of the plate denoted as C as shown in Figure 18. This was immediately followed by the oscillation of the pistons A and B (see

Figure 12) at the same frequency, but out of phase with each other by 180°. The oscillation of the pistons lasted only one cycle, that is, for 3 seconds. Thereafter, the moulding was cooled for 40 seconds under static pressure provided by both pistons each set at 40 % of the maximum hydraulic pressure of the pump. This was followed by the ejection of the moulded component.

The flexural properties of the moulding were determined by 3-point flexural testing at room temperature (23°C). Strip samples were cut from the mouldings as shown in Figure 19. The flexural properties of the samples were tested at a cross-head speed of 0.7 mm/min.

The tensile strength of the mouldings was determined by using tensile test bars which were shaped from the above mentioned rectangular strips as shown in Figure 20. The tensile test was conducted at room temperature (23°C) and at a cross-head speed of 5 mm/min.

The flexural and tensile test results are given in Table 1.

The temperature-time chart shown in Figure 13 illustrates an example of the course of temperature changes at some positions (at points A, E and F in Figure 3) of the metal mould after high-frequency induction heating using the same pre-heating conditions as in Example 1.

REFERENCE 1

(The Production of Reference Moulding to Example 1)

In the production of reference mouldings, the same injection moulding machine, same mould and the same resin composition as in Example 1 were used.

The processing conditions used were:

(a) Resin temperature: 240 °C

Mould temperature: 60 °C

Cooling time: 40 seconds

Injection pressure: 100 bar

Holding pressure: 40 bar

N.B. The production of the reference mouldings was conducted without mould pre-heating and the application of periodic force, i.e. no piston oscillation.

(b) As the processing conditions used in (a) above, without mould pre-heating but using the same periodic force as used in Example 1.

(c) As the processing conditions used in (a) above with mould pre-heating as used in Example 1, but without the application of periodic force, i.e. no piston oscillation.

The samples for mechanical properties testing were prepared by the same method as in Example 1 and are also included in Table 1.

TABLE I

	Moulding Process				
	Example 1	Reference Mouldings			
		(a)	(b)	(c)	(*)
Flexural modulus (GPa)	6.57 (0.36)	5.67 (0.25)	6.33 (0.54)	5.59 (0.19)	6.00 (0.31)
Flexural strength (MPa)	144.4 (7.6)	105.9 (6.6)	123.9 (9.8)	111.7 (5.5)	131.9 (7.4)
Tensile strength (MPa)	94.20 (9.86)	56.69 (4.37)	85.35 (8.87)	57.97 (1.21)	76.99 (11.10)
Appearance	Excellent	Poor	Poor	Excellent	Poor

(): Standard deviation based on more than fourteen (14) samples

- (a): Conventional moulding without mould pre-heating and without application of a periodic force
- (b): Moulding with periodic force but without mould pre-heating
- (c): Moulding with mould pre-heating but without a periodic force
- (*): The same specimens as (a) (which contains a weldline) were used but the region of test was weldline-free.

The flexural properties measured are greatest for mouldings produced as in Example 1 and as compared to the Reference mouldings. The fact that the properties of mouldings of Example 1 are also greater than (*) mouldings (weldline-free) strongly suggests the advantage of this example of moulding

process.

The tensile strengths of the Example 1 mouldings are again compared to the Reference mouldings. The increase is more marked than recorded for the (b) mouldings. This suggests the clear advantage of using both the periodic force by piston oscillation and the mould pre-heating, as suggested by the tensile strength value of (c) mouldings which is markedly lower than the tensile strength value of the mouldings referred to in Example 1.

To conclude, the mechanical properties shown in Table 1 clearly indicate the significant improvements gained by using the combination of mould pre-heating effected by high-frequency induction heating and periodic forces provided by piston oscillation.

With respect to the surface appearance of mouldings, the use of high-frequency induction heating distinctly shows a much superior finish than any of the mouldings whose production did not use the high-frequency induction heating method. Although the use of the high-frequency induction heating method without the application of periodic force gave excellent surface finish, the translucent mouldings exhibited evidence of a weldline located within the core of the mouldings. -However, the use of both high-frequency induction heating and a periodic force produced the most superior surface finish without any visual evidence of a weldline, either in the skin or in the core region.

EXAMPLE 2

In this Example, the injection moulding machine, the high-frequency induction heating and the shear control devices were arranged essentially as shown in Figure 1 and Figure 12. The position of the high-frequency induction heating device is shown in (A) of Figure 12, and the arrangement of applying of

periodic forces is shown in (B) of Figure 12.

An ABS resin composition containing 30 % by weight of glass fibre was injection moulded using a twin barrel injection moulding machine. A split mould made of steel was used which provided for moulding a flat square piece A having a thickness of 1.5mm (Figure 18) through opposing fan gates B and B' each measuring 56.10x20x6 mm as shown in Figure 18.

The inductor was placed between the mould halves and energised up to a high frequency output of 20KHz at 15KW for 12 seconds.

The temperatures of the injection barrels were adjusted so as to obtain a resin mixture temperature of 240°C. Before injecting the resin mixture into the mould, the inductor prepared as above was lowered between the two mould halves by robot application. The distance between the inductor and moving half mould surface was 8mm, and the distance between the inductor and fixed half mould surface was 15 mm. After activating the inductor at 20 KHz at 15KW for 12 seconds, the split mould was retracted in order to withdraw the inductor before the mould was closed again. Then, the molten ABS resin composition containing glass fibre was injected into the mould through the manifold at an injection pressure of 100 bar. The mould cavity was filled through the fan gates to produce a weld line at the centre of the plate denoted as C as shown in Figure 18. This was immediately followed by the oscillation of the pistons A and B (see Figure 12) at the same frequency, but out of phase with each other by 180°. The oscillation of the pistons lasted four cycles, that is, for 12 seconds. Thereafter, the mould was cooled for 20 seconds under static pressure provided by both pistons each set at 40 % of the maximum hydraulic pressure of the pump. This was followed by the ejection of the moulded component.

The flexural properties of the moulding were determined by 3-point flexural testing at room temperature (23°C). Strip samples were cut from the mouldings as shown in Figure 19. The flexural properties of the samples were tested at a cross-head speed of 0.7 mm/min.

The tensile strength of the mouldings was determined by using tensile test bars which were shaped from the above mentioned rectangular strips, as shown in Figure 20. The tensile test was conducted at room temperature (23°C) and at a cross-head speed of 5 mm/min.

The flexural and tensile test results are given in Table 2.

REFERENCE 2

(The Production of Reference Mouldings to Example 2)

In the production of reference mouldings, the same injection moulding machine, same mould and same resin composition as in Example 2 were used.

The processing conditions used were:

Resin temperature: 240 °C

Mould temperature: 50 °C

Cooling time: 20 seconds

Injection pressure: 100 bar

Holding pressure: 40 bar

N.B. The production of the reference mouldings was conducted without mould pre-heating and the application of periodic force, i.e. no piston oscillation.

The samples used for mechanical properties testing were prepared by the same method as in Example 2.

The flexural and tensile test results are given in Table 2.

The stress-strain curves produced in the tensile tests are shown in Figure 14; (a) indicates the stress-strain curve in accordance with the process used in Example 2; (b) indicates the stress-strain curve in accordance with Reference 2.

The stress-displacement curves produced during flexural tests are shown in Figure 15; (a) indicates the stress- displacement curve in accordance with the invention in accordance with Example 2; (b) indicates the stress-displacement curve in accordance with Reference 2.

TABLE 2

Moulding process	Example 2	Reference 2 (Conventional Mouldings)
Flexural modulus (GPa)	6.96 (0.33)	6.05 (0.38)
Flexural strength (MPa)	141.8 (5.0)	86.66 (3.7)
Tensile strength (MPa)	85.03 (4.01)	48.62 (2.61)
Appearance	Excellent	Poor

(*) Standard deviation based on more than fourteen (14) samples

These results show that mechanical properties of moulded articles produced by the above-mentioned processes can be substantially improved by the application of a periodic force. Such processing causes the weld strength of glass fibre reinforced mouldings to increase over that of the strength of the part without internal weldlines.

Moreover it will be seen that the flexural modulus of the specimens prepared in the Example is increased by 16%, relative to the comparative specimen made by conventional injection moulding.

The appearance of the moulded article surface reproduced the preheated mould cavity (moving side mould) at a predetermined temperature was excellent and showed no fault such as a weldline, streaks or exposure of glass fibre on the outer face.

EXAMPLE 3

In this Example, the injection moulding machine, the high-frequency induction heating and shear control devices were arranged essentially as is shown in Figure 1 and Figure 12. The position of the high-frequency induction heating is shown in (A) of Figure 12, and the arrangement for the application of periodic forces is shown in (B) of Figure 12.

A clear ABS resin composition containing 2% by weight of aluminium flake having a medium flake diameter of 75 μm was injection moulded using a twin barrel injection moulding machine. A split mould made of steel was used which provided for moulding a flat square piece A having a thickness of 1.5mm (Figure 18) through opposing fan gates B and B' each measuring 56.10x20x6 mm as shown in Figure 18.

The inductor was placed between the mould halves and energised up to a high frequency output of 20KHz at 15KW for 22 seconds.

The temperatures of the injection barrels were adjusted so as to obtain a resin mixture temperature of 240°C. Before injecting the resin mixture into the mould, the inductor prepared as above was lowered between the two mould halves by robot operation. The distances between the inductor and mould surfaces were 8 mm. After actuating the oscillation at 20 KHz at 15KW for 22 seconds, the split mould was retracted to draw out the inductor before it was closed again. Then, the molten ABS resin composition containing aluminium flake was injected into the mould through the manifold at an injection pressure of 100 bar. The mould cavity was filled through the fan gates to produce a weld line at the centre of the plate denoted as C, as shown in Figure 18. This was immediately followed by the oscillation of the pistons A and B (see Figure 12) at the same frequency, but out of phase with each other by 180°. The oscillation of the pistons lasted only one cycle, that is, for 3 seconds. Thereafter, the moulding was cooled for 20 seconds under static pressure provided by both pistons each set at 40 % of the maximum hydraulic pressure of the pump, and then cooled for 70 seconds without static pressure. This was followed by the ejection of the moulded component.

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The appearances of the moulded articles are summarised in Table 3.

REFERENCE 3

(The Production of Reference Mouldings to Example 3)

In the production of reference mouldings, the same injection moulding machine, same mould and same resin composition as in Example 3 were used.

The processing conditions used were:

(a) Resin temperature: 240 °C

Mould temperature: 50 °C

Cooling time: 40 seconds

Injection pressure: 100 bar

Holding pressure: 40 bar

N.B. The production of the reference mouldings was conducted without mould pre-heating and the application of periodic force, i.e. no piston oscillation.

(b) As the processing conditions used in (a) above, without mould pre-heating but using the same periodic force as used in Example 3.

(c) As the processing conditions used in (a) above with mould pre-heating as used in Example 3, but without a periodic force, i.e. no piston oscillation.

A summary of the appearance of moulded articles is given in Table 3.

TABLE 3

Moulding Process	Appearance of moulded article
Example 3	Excellent. The surface of the moulded article showed a complete absence of the weldline mark without any evidence of faults such as flow marks. Exposure of aluminium flake was absent on any other surface.
Reference 3 (a)	The appearance of the moulded article showed a weldline mark and the appearance of moulded article was rough.
Reference 3 (b)	The weldline mark was only slightly affected by application of periodic force. However, the appearance of the moulded article showed a weldline mark, and the appearance of moulded article was rough.
Reference 3 (c)	The surface finish of the moulding was excellent with no exposure of aluminium flake on the outer surface. However, a weldline could be seen clearly in the core of the moulded article.

Photographs of the moulded article are shown in Figures 16 and 17. Figure 16 shows the moulded article in accordance with Example 3. Figures 17(a), 17(b) and 17(c) shows the moulded articles in accordance with Reference 3(a), 3(b) and (c).

Thus, it was found that the process of this Example showed a dramatic and positive effect on the weldline defect and the surface finish.

The disclosures in British patent application 9507533.8, from which this application claims priority, and in the abstract accompanying this application are incorporated herein by reference.

CLAIMS

1. An injection moulding process for moulding a molten material, containing at least one kind of thermoplastic resin, in a mould having a mould cavity and at least one channel communicating with the mould cavity, each channel entering the mould at a respective mould inlet, the process including the steps of:

heating inner surface areas of the mould to a temperature above the heat distortion temperature of the material;

supplying the molten material into the mould by way of at least one channel and subjecting the molten material to a propelling force, sufficient to propel it through the channel into the mould;

causing the molten material in the mould to solidify;

applying periodic forces to the material in the mould at a plurality of spaced-apart regions, first and second of the regions being located either side of molten material in the mould cavity, the periodic force being applied with a difference in phase so as to cause shear of molten material within the mould cavity between the first and second regions;

cooling the mould below the heat distortion temperature of the resin while or after applying the periodic force;

and then opening the mould, and removing the moulded article.

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2. A moulding process according to Claim 1 in which the inner surface area of the mould is heated by high-frequency induction heating.

3. A moulding process according to Claim 1 or 2, wherein the mould is heated substantially to the melt processing temperature.

4. A moulding process according to Claim 1, 2 or 3, wherein the periodic forces are applied as the mould becomes filled with molten material.

5. A moulding process according to any preceding claim, in which the molten material comprises a polymer material.
6. A moulding process according to Claim 5, in which the polymer material comprises a thermosetting resin.
7. A moulding process according to any preceding claim, in which the material contains fillers and/or additives.
8. A moulding process according to any preceding claim, in which the material contains aluminium flakes.
9. A moulding process according to any preceding claim, comprising the step of forming a skin layer to the surfaces of the mould cavity, the skin layer being applied to the material during moulding thereof.
10. An injection moulded article produced by a process according to any preceding claim.
11. An injection moulded article according to Claim 10, in which the micromorphology of the whole moulded article is controlled.
12. An injection moulded article according to Claim 10 or 11, in which the orientation of the whole moulded article is controlled.

13. An injection moulded article according to Claim 10, 11 or 12, in which the surface of the moulded article has a smooth skin layer constituted substantially of only a resin component over the outer surface of a core of the article.
14. An injection moulded article according to any one of Claims 10 to 13, in which the moulded article consists of at least two kinds of materials which contain different filler and/or additives and/or neither filler nor additives.
15. A moulding process substantially as hereinbefore described with reference to the accompanying drawings.
16. An injection moulded article substantially as hereinbefore described with reference to the accompanying drawings.



Application No: GB 9510532.6
Claims searched: 1-16

Examiner: Monty Siddique
Date of search: 22 May 1996

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.O): B5A (AD20, AD34, AT14P, AT17J)

Int CI (Ed.6): B29C 45/00 45/47 45/73

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	GB 2170142 A (NRDC) applying out of phase periodic forces to cause shearing of molten material	1 at least
Y	GB 2081171 A (ASAHI-DOW) heating mould areas by high frequency induction heating	1 at least
A	WPI Abstract Accession No. 68-26687Q/00 & FR 001553319 A (PRALONG) 29.01.68 (see abstract)	1 at least

X Document indicating lack of novelty or inventive step	A Document indicating technological background and/or state of the art.
Y Document indicating lack of inventive step if combined with one or more other documents of same category.	P Document published on or after the declared priority date but before the filing date of this invention.
& Member of the same patent family	E Patent document published on or after, but with priority date earlier than, the filing date of this application.